ARTICLE III.

IS THE ACTION OF THE MEDULLA OBLONGATA IN NORMAL RESPIRATION REFLEX?

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IN connection with a series of experiments published in 1877, the question occurred to my mind whether or not the action of the medulla oblongata in normal respiration could strictly be classed among those operations recognized by physiologists as reflex. That the medulla oblongata is the centre presiding over certain reflex phenomena, acting through some special nerves, there can be no doubt. This centre seems to serve as a coordinator of the muscles of expression, and it has certain reflex functions connected with the respiratory muscles, such as coughing, sneezing, etc. In certain instances, also, in which respiration is temporarily suspended, a stimulation of parts of the general surface, as by a dash of cold water, will excite respiratory movements. Such an action as the one last mentioned might properly be called reflex; but the phenomena which I here propose to consider are those of ordinary, normal respiration and the exaggerations of the respiratory sense which amount to a more or less intense feeling of want of air.

The general view under which physiologists have been accustomed to regard the respiratory movements as reflex is the following: It has been thought that there existed in some part of the organism or in the system at large a certain sense, which may be called the sense of want of air, the respiratory sense, or the *besoin de respirer* of the French, dependent upon either an actual or an impending deficiency of oxygen or upon an impression produced by the circulation of blood containing carbonic acid in parts that should normally receive oxygenated blood. This "respiratory sense" has been taken as the starting-point of the respiratory acts. Regarding a reflex phenomenon as involving an impression conveyed by afferent nerves to a nerve-centre, which impression, by the action of the nerve-centre, is converted into a stimulus and is reflected along certain efferent nerves to muscles, the conditions of the operation of reflex action in ordinary respiration have been regarded as complete. The respiratory sense, according to this view, is conveyed by certain centripetal nerves to the medulla oblongata, and here it is converted into a stimulus which is conveyed by the proper centrifugal nerves to the respiratory muscles, and there follows an act of inspiration.

My principal object, in this article, is to discuss the question of the so-called reflex action of the medulla oblongata in respiration, drawing my conclusions mainly from my own experiments. I shall not, therefore, attempt to give a full account of the literature bearing upon the action of the medulla oblongata as the respiratory nervous centre, or even of the experiments which relate to its reflex function, except in so far as the latter have been followed by important advances or changes in the views of physiologists or as their history involves questions of priority.

In 1809, Legallois made a number of experiments upon rabbits, in which he showed that respiration ceased suddenly when a section of the medulla oblongata was made to include the origin of the eighth pair of nerves; but that the respiratory acts continued when the cerebrum, cerebellum, and a part of the medulla oblongata were removed by successive slices from before backward.[1] Flourens extended the observations of Legallois, and fixed the limits of the respiratory nerve-centre in the rabbit between the upper border of the origin of the pneumogastric nerves and a line drawn about a quarter of an inch below the lowest point of origin of these nerves.[2] Longet and Flourens, in later observations, restricted the limit still farther, and showed that it was confined to the gray matter of the lateral tracts, or the intermediary fasciculi.[3] Since the publication of the experiments of Flourens, nearly all physiologists have agreed that the respiratory nervous centre is situated in some part of the gray matter of the medulla, and this view I accept without reserve. Its most notable opponent, however, is Dr. Brown-Séquard. This author contends that the arrest of respiratory movements which follows destruction of the medulla is due to irritation of surrounding parts, and not to the destruction of the so-called respiratory centre; and that, in certain cases, the movements may become reëstablished after the irritation has subsided.[4] In the absence of their full confirmation by other observers, I do not regard the experiments or the conclusions of Dr. Brown-Séquard as satisfactory; and I still hold that the medulla oblongata is the centre presiding over the respiratory acts.

Marshall Hall, in his memoir on the "Reflex Function of the Medulla Oblongata and Medulla Spinalis," published in 1833, says nothing with regard to the reflex character of respiration. In the Croonian Lectures, delivered before the Royal College of Physicians in 1850, he advances the view that the normal respiratory acts are reflex and dependent upon excitation of the pneumogastric nerves by the accumulation of carbonic acid evolved in the lungs by the venous blood.[5] Subsequent observations, however, have shown that the theory proposed by Marshall Hall is incorrect; and, at the present day, it is not adopted by any physiologist of recognized authority. As early as 1839, John Reid suggested that the sense of want of air was due in a measure to the circulation of venous blood in the medulla oblongata.[1] This fact is interesting in view of the results of recent experiments which will be detailed farther on. In 1841, Volkmann made a number of experiments, the conclusion drawn from which was that the sense of want of air depends upon a certain condition of the general system as well as an impression made upon the pulmonary mucous membrane.

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[1] Legallois, Expériences sur le principe de la vie. Œuvres, Paris, 1824, tome i. p. 64. The date of these experiments is given by Legallois on page 71 of the above-mentioned work.

[2] Flourens, Système nerveux, Paris, 1842, p. 204.

[3] Longet, Traité de physiologie, Paris, 1869, tome iii. pp. 387, 388.

[4] Brown-Séquard, Recherches sur les causes de mort après l'ablation de la partie de la moelle allongée qui a été nommée point vital. Journal de la physiologie, Paris, 1858, tome i. p. 217 et seq.; and Recherches expérimentale sur la physiologie de la moelle allongée. Ibid., 1860, tome iii. p. 151 et seq.

[5] Marshall Hall, Synopsis of the Diastaltic Nervous System, London (no date), p. 43.

> "The respiratory movements appear really to be of a reflex character in the following way: The exciting agent is carbonic acid—not that which has become free in the air-passages, but that which is contained in the blood; the situation of the stimulation is in every part of the body, not alone the pulmonary mucous membrane; finally, the nerves brought into action are all nerves which conduct centripetally operating toward the medulla oblongata, not exclusively the vagus."[2]

Volkmann states, immediately following the passage just quoted, that the respiratory movements find their impulse in a "respiratory necessity," and that this originates in the entire system; that all animals require oxygen from the blood in place of the carbonic acid which they give up to the blood; and that, as soon as the blood is overcharged with carbonic acid, this "necessity" (respiratory) cannot be satisfied.

In 1861 I made a series of experiments with the view of ascertaining the situation of the respiratory sense, adopting the view, which was then almost universally received, that the respiratory acts are reflex.[3] The main points in these experiments were the following:—

When the chest was opened in a living dog, and a bellows fixed in the trachea, so long as artificial respiration was efficiently performed, the animal made no respiratory efforts. In these experiments the animals were usually etherized; but in several instances they were allowed to come from under the influence of the anæsthetic. The diaphragm and other important respiratory muscles were denuded and fully exposed to view. This was almost an exact repetition of an experiment performed by Robert Hook in 1664.

An artery was then opened and the blood was allowed to flow in a small stream. When the artificial respiration was suspended, the animal began to make respiratory efforts as soon as the blood became dark in the arteries; but, when artificial respiration was resumed, as soon as the blood became again bright red in the arteries, the respiratory efforts ceased.

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[1] Reid, An Experimental Investigation into the Functions of the Eighth Pair of Nerves, etc., Part Second. Anatomical and Physiological Researches, Edinburgh, 1848, p. 285; and Edinburgh Medical and Surgical Journal, April, 1839.

[2] Volkmann, Ueber die Bewegungen des Athems und Schluckens, etc. Archiv für Anatomie, Physiologie, und wissenschaftliche Medecin, Berlin, 1841, S. 342.

[3] Flint, Jr., Experimental Researches on Points connected with the Action of the Heart and with Respiration. American Journal of the Medical Sciences, Philada., October, 1861, p. 372 et seq.

In order to ascertain whether the sense of want of air were due to a deficiency of oxygen or to the presence of carbonic acid in the blood of the arteries, I drained the animals of blood, sometimes from a large artery and sometimes by excising the heart, at the same time keeping up artificial respiration carefully and efficiently. As the system became drained of blood, there always occurred vigorous and even violent respiratory efforts, although the lungs were kept supplied with pure air.

From these experiments I reasoned that, the respiratory movements being, as I thought, reflex, the sense of want of air depended upon a deficiency of oxygen in the system at large, and not upon the presence of carbonic acid in the blood of the arteries, for the sense seemed to be felt by the animals in my experiments when the system was drained of blood, the arteries containing no blood charged with carbonic acid.

In 1868, about seven years after the publication of my experiments in the *American Journal of the Medical Sciences*, Pflüger published a very interesting article upon the same subject.[1] In this article, a very elaborate review is given of the literature of the subject. He first refers to the opinions of various authors with regard to the question of a difference in colour between the blood of the umbilical arteries and the umbilical vein, and then goes on to state that "it is established without doubt that, after birth, there is a diminution in the quantity of oxygen in the body of the newly born, which, as the following researches will show, is the real cause of respiration." The experiments by means of which Pflüger came to the conclusion that the sense of want of air, dyspnœa, and apnœa were due to a want of oxygen in the system, consisted mainly in causing animals to breathe an irrespirable gas, such as pure nitrogen.[2]

> "Using blood-letting for ascertaining the condition of the blood during dyspnœa, I arrived at the following facts: As soon as the dog begins to breathe pure nitrogen, it is scarcely fifteen seconds before he makes violent and deep inspirations; at the end of thirty seconds, the most intense dyspnœa is observed, the blood is already almost absolutely black, which must be due to the enormously rapid tissue-metamorphosis of the animal. At the end of one minute the animal

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[1] Pflüger, Ueber die Ursache der Athembewegungen, sowie der Dyspnoë und Apnoë. Archiv für die gesammte Physiologie, Berne, 1868, Bd. i., S. 61 et seq.

[2] Rosenthal, in his work on the "Respiratory Movements," published in 1862, anticipated the experiments of Pflüger upon the influence of the insufflation of irrespirable gases upon the respiratory movements. He noted that the manifestations of dyspnœa ceased in animals when the chest had been opened and oxygen was passed through the lungs, but that they continued when, instead of oxygen, nitrogen or hydrogen was used, "although in this case the carbonic acid, as well as the oxygen, was removed from the blood." From this it appears to follow that it is not the increased quantity of carbonic acid, but the diminished quantity of oxygen which, in dyspnœa, produces the mediate or the immediate stimulation of the respiratory central organ. (Rosenthal, Die Athembewegungen, etc., Berlin, 1862, S. 4.) My own experiments were published in 1861.

is already almost asphyxiated. The respiratory movements are very infrequent or have ceased, but the heart still beats."[1]

Then follows a series of examinations of the blood under normal conditions at various times after causing an animal to breathe pure nitrogen. In one of these observations, after causing a dog to breathe nitrogen for one minute, the oxygen of the blood was found to be reduced from 14.35 per cent. to 0.2 per cent., and the carbonic acid from 36.9 per cent. to 29.9 per cent., showing a great diminution in oxygen and a considerable diminution in carbonic acid. "No one, therefore, can be of the opinion that dyspnœa and asphyxia in breathing indifferent gases is connected with the accumulation of carbonic acid."[2]

While Pflüger assumed to give a review of the literature of the subject under investigation, he made no mention of my experiments published in 1861, although the results were nearly identical with his own. Later observations and experiments, however, have convinced me that the interpretations of my earlier experiments, as well as of those made by Pflüger, were incorrect. I do not now believe that the acts of respiration are purely reflex in the sense in which this term is generally used; and I do not believe that the sense of want of air is due to a deficiency of oxygen in the system at large. I have become convinced, by experiments made in 1877, that the real cause of the sense of want of air, with its various exaggerations and modifications, is a deficiency in, or an absence of oxygenated blood in the vessels of the medulla oblongata. This opinion has been entertained by certain physiologists on theoretical grounds, but, so far as I know, it had not been sustained by direct experiment prior to 1877.

In 1877, I made a series of experiments which seemed to me to demonstrate conclusively that the sense of want of air is due to a deficiency of oxygen-carrying blood in the medulla oblongata. The details of these experiments have already been published,[3] and I shall here give merely a summary of the results.

If the chest of a dog be opened, the animal being under the influence of ether, and if artificial respiration be efficiently maintained by means of a bellows fixed in the trachea, the animal will make no respiratory efforts so long as fresh air in sufficient quantity is supplied to the lungs. This is an old experiment, dating from the time of Robert Hook, in 1664, and has been repeatedly verified.

If, air still being supplied in adequate quantity to the lungs, the aorta be tied or the system be drained of blood, the animal will make violent respiratory efforts under the influence of the sense of want of air. This is due to the fact that the oxygen cannot get to the system or to some part or parts of the system, and this demonstration was made and published by me as early as 1861. Similar results were obtained by Rosenthal, in 1862, and by Pflüger in 1868.

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[1] Pflüger, op. cit., S. 89.

[2] Pflüger, op. cit., S. 95.

[3] Flint, Jr., Experiments on the Effects upon Respiration of cutting off the Supply of Blood from the Brain and the Medulla Oblongata. New York Medical Journal, November, 1877, vol. xxvi. p. 449.

In 1877, it occurred to my mind that it was possible to ascertain by experiment whether the sense of want of air were due to a want of oxygen in the general system or in some restricted part. It being so well established that the medulla oblongata is the respiratory nervous centre, I was naturally led to look for some means of cutting off the supply of blood from this part. This can be easily done by tying the innominate artery and the left subclavian artery in a dog, in this animal the aorta giving off from the arch these two vessels which are the only sources of supply of blood to the head and the anterior extremities. The following experiment, which I copy from my article published in 1877, shows the effect of constricting the vessels given off from the arch of the aorta. This experiment is a type of many others made in my laboratory and in public demonstrations.

September 30, 1877.—A medium-sized, full-grown dog was brought completely under the influence of ether. The trachea was then opened and connected with a bellows, and artificial respiration was maintained. Over the valve of the bellows was placed a sponge, which was saturated with ether from time to time, so that the animal was kept completely anæsthetized during the experiment. The air in the bellows was also changed from time to time by pushing up the valve with the fingers and forcing out the vitiated air. The chest and abdomen were then laid open by a continuous incision in the median line, and the ribs were bent backward and secured with a strong cord tied behind the back, so that the lungs and heart were fully exposed. The pericardium was then cut away, the great vessels near the heart were isolated, and loose ligatures were thrown around the trunk of the innominate artery, the left subclavian artery, the descending vena cava, the descending portion of the aorta, and the ascending vena cava.[1] In this way, I was prepared to constrict the several vessels at will.

When these preliminary steps had been completed, the animal being entirely under the influence of ether and artificial respiration being kept up efficiently, there were absolutely no respiratory efforts, and the diaphragm, which was exposed, was quiescent.

The artificial respiration was then arrested. In forty-five seconds, the animal began to make violent respiratory efforts. Artificial respiration was then resumed, and the respiratory efforts of the animal ceased. When the artificial respiration was arrested, we first noticed a movement of the corners of the mouth at regular intervals, and then the mouth was widely opened and the diaphragm became strongly contracted, also at regular intervals. The time was taken at the first violent respiratory effort.

The animal being perfectly quiet and making no efforts at respiration, the innominate artery, the left subclavian artery, and the descending vena cava, were tied nearly simultaneously, artificial respiration being constantly and efficiently maintained. In two minutes and eight seconds, the animal began to make respiratory efforts, which continued so long as the vessels remained constricted.

The ligatures surrounding the vessels mentioned above were loosened five minutes and twenty-two seconds after they had been tied, and the respiratory efforts of the animal instantly ceased. After three minutes, artificial respiration was stopped, and the animal began to make respiratory efforts in thirty-nine and a half seconds, which ceased as soon as artificial respiration was resumed.

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[1] In the dog, the aorta gives off the innominate artery, "which gives off first the left carotid, and then divides into the right subclavian and right carotid" (Foster, "Elementary Practical Physiology," London, 1876, p. 13). The left subclavian artery arises directly from the aorta.

The descending aorta and the ascending vena cava in the chest were then tied simultaneously, the vessels arising from the arch of the aorta being free. This seemed to produce no effect, and no respiratory efforts were made by the animal for five minutes. The innominate artery and the left subclavian artery were then constricted, the aorta and ascending vena cava remaining tied. Respiratory efforts by the animal began in one minute and twenty-six seconds, although artificial respiration was maintained. These efforts ceased when the ligatures around the innominate and subclavian were loosened.

The ligatures were then removed from the descending aorta and ascending vena cava, and the innominate and left subclavian arteries were constricted, which was followed by respiratory efforts after one minute and six seconds. These efforts ceased when the vessels were freed.

The innominate artery alone was then constricted, but this seemed to produce no effect, no respiratory efforts being made by the animal for five minutes. At the end of five minutes, the left subclavian artery was constricted, the constriction of the innominate artery being maintained. The animal began to make respiratory efforts fifty-three seconds after constriction of the subclavian. These efforts ceased on loosening the ligatures.

Artificial respiration was then stopped, and the animal began to make respiratory efforts in ten seconds. The medulla oblongata was then broken up, and the experiment was concluded.

In this experiment I had the aid of my able assistant Dr. C. F. Roberts, and Mr. Gaspar Griswold, an advanced laboratory student. As the experiment progressed, it was ascertained that the vessels could be effectually constricted by making traction on the ligatures without tying. The constriction could then be instantly removed. It was also ascertained that constriction of the veins made no difference in the phenomena observed.

The general result of all my experiments made on the plan of the one just detailed was that invariably, when the innominate and the left subclavian artery were tied, the dogs began to make respiratory efforts in a little more than two minutes after the ligation, but the animals remained quiet after ligation of the aorta in the chest. The respiratory efforts continued so long as the vessels going off from the arch of the aorta remained constricted, and they ceased almost immediately when the ligatures were loosened. During all of my observations upon the effects of tying the various bloodvessels, artificial respiration was kept up constantly and efficiently. Under the view which I was led to adopt by the results of the experiments, viz., that the sense of want of air was due to a deficiency of oxygen-carrying blood in the medulla oblongata, I could not be certain that the arterial blood was entirely shut off from the medulla without tying the innominate and the left subclavian. It seemed to make no difference in the results of the experiments whether the great veins were tied or left free. In all of the experiments, the excitability of the medulla was repeatedly shown by arresting artificial respiration from time to time. The animals began to make respiratory efforts in from thirty to forty-five seconds after the arrest of artificial respiration.

The results of my experiments show that, when the flow of oxygenated blood is cut off from the parts supplied by the vessels given off from the arch of the aorta in a living animal, the sense of the want of air is excited —as is evident from the repeated and often violent respiratory efforts— although air is supplied to the lungs. Respiration will continue when all of the encephalic ganglia with the exception of the medulla oblongata have been removed; and it is well known that this (the medulla) is the sole respiratory nervous centre. We should naturally look, then, to influences operating upon the medulla oblongata for an explanation of these respiratory efforts. It does not seem that these movements can be due to an impression received by the medulla from the general system and due to want of oxygen; for, when the descending aorta is tied in the chest, no respiratory efforts are made. The movements, indeed, occur only when the medulla oblongata is deprived of blood; and the vessels which it is necessary to tie in order to produce this result involve a smaller part of the general systemic circulation than when the descending aorta is tied in the chest.

I do not assume that the view just enunciated is entirely novel, but, so far as I know, the observations made in 1877 were the first to sustain such a view by positive experimental evidence. Upon this point, I have nothing to add to what I have already stated in connection with the following quotations.[1]

"The first respiratory effort of the fœtus is thus produced by the interruption of the placental respiration, the sudden deficiency of oxygen and increase of carbonic acid in the blood (Schwartz). This change in the blood needs to take place locally only in the vessels of the medulla oblongata, in order to produce this effect; it occurs, for example, from arrest of the blood in these vessels (by ligature of the carotid arteries, Kussmaul and Tenner, Rosenthal, or by closure of the venous currents from the brain, Hermann and Escher), by which their blood becomes progressively poorer in oxygen and richer in carbonic acid" (Hermann, "Grundiss der Physiologie des Menschen," Berlin, 1870, S. 160).

"If the supply of blood be cut off from the medulla by ligature of the bloodvessels of the neck, dyspnœa is produced, though the operation produces no change in the blood generally, but simply affects the respiratory condition of the medulla itself, by cutting off its blood supply, the immediate result of which is an accumulation of carbonic acid and a paucity of available oxygen in the protoplasm of the nerve-cells in that region." (Foster, "A Text-Book of Physiology," New York, 1880, p. 377).

These quotations from Hermann and from Foster show clearly that their idea is that the sense of want of air is due to deficiency of oxygenated blood in the medulla oblongata, a view fully sustained by my own experiments. The observations of Kussmaul and Tenner, referred to by Hermann, were made with reference to the cause of the convulsions which so often occur after profuse and sudden hemorrhage. They are to be found in the elaborate memoir by Kussmaul and Tenner, "On the Nature and Origin of Epileptiform Convulsions caused by Profuse Bleeding," translated and published by the "New Sydenham Society," in 1859. Kussmaul and Tenner made a large number of experiments upon rabbits and horses, in which they observed the effects of tying the great vessels given off from the arch of the aorta. They noted, after this operation, great difficulty in respiration and violent convulsions. They did not, however, arrest the respiratory movements of the animal by artificial respiration, thus abolishing, for the time, the respiratory sense, and then note the effects of ligature of these vessels. The experiments by Rosenthal, which are referred to, are probably those contained in his work "Die Athembewegungen und ihre Beziehungen zum Nervus Vagus," Berlin, 1862. In these experiments, as I have already stated, it is shown that the respiratory efforts of an animal can be abolished by forcing atmospheric air or oxygen in large quantities through the lungs, but that the sense of want of air is felt when, in place of oxygen, nitrogen or hydrogen is employed, by this means removing the possibility of an irritation from carbonic acid. These are essentially the same as the observations made by Pflüger, in 1868. Rosenthal states very distinctly that the sense of want of air is due to want of oxygen-carrying blood in the medulla oblongata; but he does not actually demonstrate the truth of this proposition by experiments. The statements by Hermann and by Foster are apparently based upon the experiments of Kussmaul and Tenner and of Rosenthal; but I must nevertheless claim that the experiments which I have made upon this subject, which will be detailed farther on, if they should be confirmed, afford the first positive proof that the respiratory sense may be excited by cutting off the arterial supply from the medulla. There is nothing which I can find, in the experiments of Kussmaul and Tenner or of Rosenthal, which actually shows that the sense of want of air is not due to a want of oxygen in the general system.

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[1] New York Medical Journal, November, 1877, vol. xxvi. p. 452.

All the experiments that I have thus far referred to have of necessity involved placing the animals upon which the observations were made under conditions exceedingly unnatural. It cannot be assumed that, after the chest has been opened, the nerve-centres possess a degree of sensibility and a power of action entirely normal. Still, it is not easy to see how such a modification of the natural conditions can be avoided; and we must reason as best we can from the observations that have been made, keeping in view the experimental conditions.

It is certain that oxygen may be artificially supplied to the lungs in a living animal so efficiently as to abolish for the time the sense of want of fresh air to satisfy the requirements of the system for oxygen, and to cause all respiratory efforts on the part of the animal to cease.

When artificial respiration is arrested and the blood becomes dark in the arteries, when the blood is drained from the system, artificial respiration being continued, or when oxygenated blood is shut off from the medulla oblongata, the animal makes respiratory efforts.

Taking into consideration all the experiments bearing upon this point, they seem to show beyond question that, under the conditions indicated above, the sense of want of air, the stimulus, or whatever it may be that causes the animal to make respiratory efforts, depends upon some peculiar condition in the medulla oblongata.

Still, under the conditions mentioned; that is, an animal under the influence of ether with the chest opened and a bellows in the trachea, when artificial respiration is interrupted, the respiratory efforts begin in from thirty to forty-five seconds. We then have blood in the medulla oblongata, containing less oxygen and more carbonic acid than normal arterial blood and passing through the capillaries under great pressure, slowly and with difficulty. When, on the other hand, all the vessels given off from the arch of the aorta are tied, respiratory efforts begin in a few seconds more than two minutes. While this latter experiment, taken by itself, shows that shutting off the oxygen-carrying fluid from the medulla oblongata excites the sense of want of air, the question at once arises, why, when the vessels which supply the medulla oblongata are filled with blood of a venous character, is the respiratory sense excited so much more promptly than when the arteries are tied? In other words, if it be assumed that shutting off the blood from the medulla oblongata will excite the respiratory sense by cutting off the supply of oxygen, and that this will induce respiratory efforts in about two minutes, why does the simple interruption of artificial respiration, which causes blood of a venous character to go to the medulla oblongata, induce respiratory efforts in about thirty seconds?

This is a question which I have in vain attempted to solve to my entire satisfaction. When artificial respiration is arrested and the circulation is not interfered with by the tying of vessels, the venous blood passes through the lungs and back to the left side of the heart without losing its carbonic acid and without receiving a fresh supply of oxygen. Under these conditions, it passes through the great vessels given off from the arch of the aorta to the medulla oblongata as well as to others parts; and the main obstruction to the blood-current, which produces such intense engorgement of the cardiac cavities, exists in the systemic capillaries. It is fair to infer that the capillaries of the medulla are engorged as well as others. This being the condition, it is logical to assume that the oxidizing processes which normally go on in the medulla are promptly arrested; and it may also be assumed, for sake of argument, that this arrest of oxidation excites the sense of want of air. It does not appear how any experiment can be devised in which the venous blood could be admitted in such quantity to the medulla, at the same time maintaining the normal supply of oxygen and the uninterrupted performance of normal oxidation in this particular part.

On the other hand, suppose that the great vessels given off from the arch of the aorta be tied. While the supply of fresh arterial blood is thus cut off from the medulla, it is well known that the contraction of the vessels beyond the point of ligation—which is slow and gradual, as is characteristic of non-striated muscular tissue—will still force the small quantity of blood which these vessels contain, through the medulla. My experiments show that the supply of arterial blood to the medulla need not be very considerable in order to satisfy the respiratory sense. Constriction of the innominate artery alone does not induce respiratory efforts. No respiratory efforts are made when both carotids and both vertebral arteries are constricted. These efforts, indeed, occur only when the innominate and the left subclavian are tied, or when ligatures are applied to both carotids, both vertebrals, and both subclavians.

Reasoning from these facts and inferences, the following is the only explanation that I can offer of the rapid excitation of respiratory efforts by simple arrest of artificial respiration, as compared with the effects of tying the vessels given off from the arch of the aorta :—

When artificial respiration is interrupted, the normal oxidizing process in the medulla oblongata is promptly arrested and respiratory efforts begin in from thirty to forty-five seconds. When, on the other hand, the vessels which supply blood to the medulla are tied, the contraction of the muscular coats of the vessels beyond the points of ligation for a certain time forces a small quantity of arterial blood to the medulla, and it is only when this ceases that the want of oxygen is felt. This may be the reason why the arrest of oxidation in the medulla is later when the vessels are tied than when artificial respiration is interrupted.

When it is proven, as I think it has been proven conclusively, that an animal, after the respiratory movements have been arrested by artificial respiration, will make respiratory efforts when the supply of oxygen-carrying blood is shut off from the medulla oblongata, the question arises with regard to the application of this experimental fact to the mechanism of normal respiration.

Cause of the Normal Rhythmical Movements of Respiration.—The normal, rhythmical movements of respiration are excited and regulated by the medulla oblongata, which is the sole respiratory nervous centre. Under ordinary physiological conditions, the exciting cause of these movements, whatever it may be, is unconscious, and the muscular acts by which air is introduced into the lungs take place without efforts of the will. In other words, the movements of ordinary respiration are unconscious and involuntary. That these propositions are correct, has been proven by experiments that are perfectly familiar to physiologists. When all the nerve-centres that are known to have any relations to sensation and voluntary movements are destroyed, the medulla oblongata remaining intact, the rhythmical movements of respiration persist. When the medulla oblongata is destroyed, the other nerve-centres remaining intact, the respiratory movements are instantly arrested. The cause of this arrest of respiratory movements following destruction of the medulla is explained by the following proposition :—

The medulla oblongata is the only nerve-centre capable of appreciating the unconscious sense of want of air, and, consequently, when this centre is destroyed, the sense of want of air is not felt, and no true respiratory movements can be excited. In the same way, when oxygen is freely supplied to the blood of a living animal by artificial means, no sense of want of air exists and no respiratory efforts occur. In the fœtus *in utero*, so long as oxygen is supplied to the blood by the placenta, no respiratory efforts are made ; but, when the placental circulation is interrupted, the sense of want of air is developed and respiratory efforts occur. This may take place, as is well known, before birth.

My experiments, published in 1877, show most conclusively that the sense of want of air is developed and respiratory efforts are excited, not necessarily by a possible irritation due to the circulation of venous blood in the medulla oblongata, but by cutting off from the medulla the supply of oxygen. This occurs when the respiratory acts have been arrested by supplying air to the lungs artificially.

Under ordinary physiological conditions, the heart-beats numbering seventy-two, and the respirations eighteen per minute, the following is probably the mechanism of the flow of blood through the capillaries of the lungs and the vessels of the medulla oblongata :—

The venous blood from the general system is sent to the lungs by the action of the right ventricle, the intermittent force of which is destroyed by the elasticity of the pulmonary artery and its branches, until the current in the pulmonary capillaries becomes nearly or quite steady and continuous. This venous blood is poor or deficient in oxygen and rich in carbonic acid. As it passes through the lungs, it gives off its carbonic acid and appropriates oxygen. In the pulmonary parenchyma, the composition of the air is tolerably uniform; that is, it contains a certain proportion of oxygen and of carbonic acid gas. But, at the same time, the air in the pulmonary cells has a tendency to an increase in its proportion of carbonic acid with a diminution in its oxygen; for the venous blood, as it passes through the pulmonary capillaries, is constantly giving off carbonic acid and taking up oxygen. This tendency to a diminution in oxygen and an increase in carbonic acid in the contents of the air cells progressively increases from the completion of any single inspiratory act to the beginning of another. When, however, a new act of inspiration occurs, fresh oxygen is introduced into the lungs, which supplies the place of a certain quantity of carbonic acid thrown off by the preceding expiration. That this occurs is sufficiently evident; and it is illustrated by the fact that, when expiration is voluntarily retarded, the expired air becomes much richer in carbonic acid and poorer in oxygen than it is under ordinary conditions.

On the other hand, the left ventricle is sending arterial blood received from the lungs to all parts of the system, including the medulla oblongata. The elasticity of the aorta and of its branches gradually extinguishes or absorbs the intermittent force of the heart, so that the blood flows in a steady and continuous stream through the capillaries of the medulla. But, as the tendency of the air in the pulmonary parenchyma is to progressively increase its proportionate quantity of carbonic acid and to diminish its oxygen between two inspiratory acts, the tendency of the blood coming from the lungs and sent by the left ventricle to the medulla oblongata is to become progressively poorer in oxygen. After about four revolutions of the heart (assuming that the proportion of the beats of the heart to the respiratory acts are as four to one), the quantity of oxygen supplied to the medulla oblongata has become so far diminished that there occurs an unconscious sense of want of air, and this excites a new inspiratory act. So it is, in all probability, that the normal, rhythmical acts of inspiration are periodically excited; and anything, like violent muscular exercise, that increases the activity of the consumption of oxygen, of necessity increases the number of respirations per minute.

In my opinion, in the explanation just given of the cause of the rhythmical acts of respiration, we have gone as far as we can, in the present condition of physiological knowledge, without becoming involved in unprofitable speculation and in a discussion of hypotheses not justified by established facts. All that we can at present positively assume to be true, is that respiratory movements are excited by a want of oxygen in the substance of the medulla oblongata; and I know of no reasonable theory which will explain the exact mode of action of the oxygen of the blood upon any of the anatomical elements of the respiratory nervous centre. Still, it may not be uninteresting to refer to an explanation, proposed by Pflüger[1] in 1868, and advanced again in 1878 by Burkart, the substance of which is contained in the following quotation:—

> "1. The ganglionic cells of the respiratory centre produce, when there is a deficiency of oxygen, a readily oxidizable substance. 2. This substance performs its function, through a certain degree of production and accumulation, as a stimulus to the very cells that are concerned in its production. 3. The oxygen of the blood, that is of the tissues, operates against the production and accumulation, and consequently the stimulating action of this hypothetical substance thus restrained or removed. The capacity of the ganglionic cells to produce, in a greater or less degree, by a deficiency of oxygen, this substance which excites respiratory movements, is measured by the vital energy of the cells, as far as this vital energy, or better the energy of the process of oxidation, relates to the demand for oxygen on the part of the cells. The production of the hypothetical substance is merely the vital expression of the ganglionic cells of the respiratory centre through a deficiency in oxygen, and it ceases with the life of the cells themselves."[2]

The above quotation, which it was somewhat difficult to render into idiomatic English, embodies a theory which may be more clearly expressed as follows:—

The nerve-cells of the respiratory centre are constantly producing a hypothetical substance which acts as a stimulus to the muscles of inspiration. As the arterial blood passes through the capillaries of the medulla, its oxygen combines with this hypothetical substance, which is thus destroyed, or at least its action as a stimulus to the muscles of respiration is arrested. The quantity of this substance existing in the cells of the medulla is regulated by the supply of oxygen, and this regulates the degree of stimulation of the respiratory muscles. The production of this hypothetical substance is a manifestation of the vital energy of the cells, and this production ceases with the life of the cells.

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[1] Pflüger, Ueber die Ursache der Athanbewegungen, sowie der Dyspnoë und Apnoë. —Archiv für die gesammte Physiologie, Bonn, 1868. Bd. i., S. 90.

[2] Burkart, Studien über die automatische Thätigkeit des Athemcentrums und über die Beziehungen desselben zum Nervus Vagus und anderen Athemnerven.—Archiv für die gesammte Physiologie, Bonn, 1878, Bd. xvi. S. 436.

The theory which I have proposed involves the following simple propositions deduced mainly from my experiments published in 1877:—

1. When the respiratory nervous centre is fully supplied with oxygen by means of artificial respiration, this centre gives off no stimulus to the muscles of respiration and no respiratory efforts occur.

2. When there is a deficiency in the supply of oxygen to the respiratory nervous centre, the stimulus which gives rise to inspiratory efforts is generated, and this stimulus and the respiratory efforts which follow are active and vigorous in proportion to the extent and duration of the deficiency of oxygen.

3. In normal respiration, expiration being mainly passive, the rhythm and extent of the inspiratory acts are regulated by the quantity of oxygen supplied to the medulla oblongata. Thus, when there is a tendency to a deficiency of oxygen in the arterial blood, as its proportion must gradually and progressively diminish from the termination of one inspiratory act to the beginning of another, this need of oxygen, or unconscious sense of want of air, induces a stimulus which leads to the introduction of fresh air into the lungs.

4. As oxygen can get to the medulla oblongata only through the blood, serious disturbances of the circulation are always attended with an exaggeration of the respiratory sense, although the lungs may be freely supplied with pure air.

The theory of Burkart involves the assumption of the existence of a "readily-oxidizable substance" which the cells of the medulla oblongata have a constant tendency to produce and which the oxygen of the blood has a constant tendency to destroy. Burkart assumes that this hypothetical substance acts as a stimulus to the muscles of inspiration; I contend that we can go no farther in our explanation of the generation of the respiratory stimulus than to state the fact, which I have demonstrated experimentally, that the sense of want of air, be it unconscious, as in ordinary respiration, or conscious, as it is when we experience a sense of suffocation, is due to a deficiency in the supply of oxygen to the respiratory nervous centre.

Cause of the Conscious and Exaggerated Movements of Respiration in Dyspnœa.—In ordinary respiration, the sense of want of air, which is the starting point of the stimulus that gives rise to the respiratory acts, is entirely unconscious, and the acts of inspiration are involuntary and automatic. Even when there is a slight deficiency in the proper aëration of the blood, as occurs from the vitiated atmosphere of a crowded room, we experience merely an indefinite sense of oppression, and the respiratory movements are still of the same involuntary character. But when there occurs any serious interference with the passage of fresh air to the pulmonary parenchyma, or an obstruction to the flow of arterial blood to the medulla oblongata, as in certain pulmonary and cardiac diseases, the sense of want of air is exaggerated until we become conscious of pulmonary oppression or impending suffocation. Under such conditions, many muscles that are not usually brought into action in inspiration are used, partly by an effort of the will. This is simply an exaltation and extension of the normal respiratory sense, so that it reaches the true centres of sensation, causing a voluntary increase in the number and extent of the inspiratory acts. The sense of suffocation, indeed, differs from the normal unconscious respiratory sense merely in degree, and in the fact that the former operates on the centres of ordinary sensation through sensory nerves, while the latter is confined to the medulla oblongata. Having once ascertained definitely the cause of the normal sense of want of air, we can readily understand how an exaggeration of the conditions which give rise to the natural automatic movements of respiration may produce those sensations which attend the various degrees of suffocation. As more remote consequences of asphyxia, we observe insensibility, an arrest of the circulation by engorgement of the heart, and finally the sensibility of the medulla oblongata disappears. As a general rule, when the action of the heart has ceased from asphyxia, even the most efficient artificial respiration fails to restore the respiratory function, for the reason that it is only by the action of the heart that blood can be sent to the medulla. While, however, the heart continues to act, although its contractions may be very feeble, it is within the limits of possibility to revive the functions of the medulla by artificial respiration.

There are certain agents which seem to affect the medulla directly, such as narcotics and anæsthetics. In poisoning by opium, the frequency of the respiratory acts is diminished and they may be arrested. All experimenters must have frequently observed arrest of respiration by the administration of anæsthetics to animals. In such instances, if the heart continue to beat, it is generally possible to revive the respiratory function by artificial insufflation of the lungs. In most cases of suspended respiratory action from any temporary cause, although galvanism, sudden and active stimulation of the surface, etc., may aid in restoration, the main reliance should be upon persistent and efficient artificial respiration.

Cause of the first Respiratory Act after Birth and of Respiratory Efforts in Utero.—No one doubts, at the present day, that the blood from the placenta furnishes to the fœtus *in utero* all the oxygen demanded for the function of respiration; and it is unnecessary to cite authorities to show that the blood of the umbilical vein contains oxygen, as this fact has long since been established. If the uterus of an animal far advanced in gestation be opened, an experiment which I have frequently made upon cats and dogs, the fœtuses for a time will make no respiratory efforts; but compression of the umbilical vessels of one will cause it to make very violent movements of inspiration, while the others will remain quiet so long as the placental circulation is uninterrupted. The umbilical vein carries its blood to the vena cava ascendens, thence to the left side of the heart through the foramen ovale, and thence to the upper extremities and head, including, of course, the medulla oblongata. Thus the blood that is most highly oxygenated is supplied to the medulla; and the aorta below the arch receives, through the ductus arteriosus, the blood from the right ventricle, which contains a much smaller quantity of oxygen than the blood distributed through the vessels given off above. Cutting off the flow of blood from the placenta is almost equivalent, therefore, to tying the vessels of the arch of the aorta. When this is done, the flow of oxygenated blood to the medulla is arrested, and there follows a sense of want of air which induces a stimulus that is sent to the muscles of inspiration. Air is then for the first time taken into the lungs, and the conditions of the circulation are changed. The lungs are now distended with air, and the pulmonary vessels are dilated, so that the right ventricle supplies the pulmonary capillaries, instead of sending the venous blood, as before, in greatest part through the ductus arteriosus. The pulmonary circulation being thus established, the conditions rapidly assume the character observed in the adult.

It is evident, from the experiments already noted, showing the effects of compression of the umbilical vessels, that an abnormal condition *in utero*, in which there is serious interference with the placental circulation, may induce inspiratory efforts in the fœtus, and that the liquor amnii may thus find its way into the air-passages.

Are the Normal Respiratory Movements either entirely or in part Reflex, in the Sense in which the term Reflex is ordinarily understood by Physiologists?—This question is the one which naturally arises as a logical sequence of the experiments I have described and of the deductions that I have drawn from the ascertained facts. The most important of these facts is the following: When the medulla oblongata is freely supplied with oxygen-carrying blood in a living animal, this being effected by artificial insufflation of the lungs, there are no inspiratory efforts. The animal makes respiratory efforts as the supply of oxygen to the medulla diminishes; and the want of oxygen alone is capable of inducing the stimulus to the muscles, which gives rise to the efforts to introduce air into the lungs. It is evident that the stimulus, under these experimental conditions, which was formerly thought to be reflex and produced by a certain impression conveyed to the medulla by centripetal nerves, really takes its origin in the medulla itself; that the respiratory sense, so called, is due to some alteration in the conditions of the medulla, which depends upon the supply of oxygen-carrying blood; and, finally, that this alteration does not of necessity involve any impression received through afferent nerves. Viewed in this way, when a living animal, in which the respiratory movements have been for the time arrested by artificial insufflation of the lungs, makes inspiratory efforts following the operation of shutting off the blood-supply from the medulla, the stimulus which gives rise to these efforts cannot properly be called reflex.

I shall leave out of the question under consideration various modifications of the respiratory acts, such as coughing, sneezing, etc., and the influence of certain unusual impressions made upon the surface, as by a cold douche, restricting the discussion to the normal respiratory movements.

It is well known that a relatively strong galvanic current applied to the pneumogastric nerves in the neck or to certain branches of the pneumogastrics (the superior and the inferior laryngeals), will instantly arrest respiration. This action is reflex, as is shown by the fact that galvanization of the central ends of the divided nerves influences respiration, while the stimulus applied to the peripheral ends has no effect. The effect of powerful galvanization of the pneumogastrics and of certain of their branches is marked and constant; at the same time, galvanic stimulation of some of the nerves of general sensibility has been observed to arrest respiratory movements, although this result is not invariable. When the respiratory movements are completely arrested by galvanization of the pneumogastrics, it is always the same for the general movements of the animal, which remains motionless.[1] On the other hand, "a feeble excitation accelerates the respiration; a more powerful excitation retards it; a very powerful excitation arrests it. These words 'feeble' and 'powerful' having, it is understood, only a relative sense for any one animal, and under certain conditions: what is feeble for one would be powerful for another, etc."[2]

As far as we can apply these experimental facts to the physiology of ordinary respiration, it seems that the nerves, the action of which is brought into play under physiological conditions, must be mainly, if not exclusively, the pneumogastrics. These nerves have their origin at the medulla oblongata, which undoubtedly is the sole respiratory nervous centre; they are distributed to the entire respiratory apparatus from the larynx to the deepest parts of the lungs; they are the only nerves belonging to the cerebro-spinal system that are distributed to the larynx, trachea, bronchi, and the pulmonary parenchyma; while they are not distributed to the respiratory muscles, except the intrinsic muscles of the larynx, they are capable, by reflex action, of exerting a very marked influence over the respiratory movements. In discussing, then, the question of reflex nervous action in normal respiration, the argument may properly be confined to the pneumogastrics.

The curious and interesting respiratory phenomena observed in living animals after section of both pneumogastrics are very important. When both pneumogastrics are divided in the neck, the excitation directly produced by their section momentarily accelerates the respiratory movements.

[1] Bert, Leçons sur la physiologie comparée de la respiration, Paris, 1870, p. 490.

[2] Bert, *loc. cit.*

In very young animals, in which the cartilages of the larynx are comparatively soft and pliable, the paralysis of the inferior laryngeal nerves, which preside over the respiratory movements of the glottis, often produce speedy suffocation from closure of the glottis during the inspiratory act; but in most adult animals the walls of the larynx are sufficiently rigid to enable the acts of inspiration to be carried on without serious obstruction. In such animals, for a few seconds, the number of respiratory acts may be increased, but as soon as they become tranquil, the number is very much diminished, and the movements change their character. The inspiratory acts become unusually profound and are attended with excessive dilatation of the thorax. Under these conditions, I have seen the number of respirations fall from sixteen or eighteen to four per minute.

In discussing the possible reflex influences upon the normal respiratory movements which may operate through the pneumogastrics, I shall make use of a very interesting suggestion made by Rosenbach, in 1878. In a brief note upon the "Influence of Stimulation of the Vagus upon Respiration," Rosenbach proposes the theory that this nerve (the vagus) is the vaso-motor nerve of the medulla oblongata, and that it contains fibres which contract, and fibres which dilate the bloodvessels. This idea is presented by Rosenbach simply as an hypothesis, which he "hopes later to be able to establish by experiments."[1]

I may now state, in continuing my argument, the following propositions, all of which, except the last, I assume to be facts that have been established experimentally:—

1. A deficiency in the quantity of oxygen supplied to the medulla oblongata through the arterial blood circulating in its substance will, of itself, give rise to a stimulation of the muscles concerned in the act of inspiration.

2. A relatively feeble galvanic stimulation of the pneumogastric nerves increases the frequency of the inspiratory acts; a stronger stimulation may diminish their frequency; and a very powerful stimulation arrests the respiratory movements. The action in these instances is reflex and not direct.

3. Section of both pneumogastric nerves in the neck, in most adult animals, very greatly diminishes the frequency of the respiratory acts.

4. The pneumogastric nerves possibly contain vaso-motor filaments which are capable of regulating and modifying the supply of blood to the vessels of the medulla oblongata.

If these propositions be taken as the basis of a theory of the mechanism of normal respiration, the following seem to be the natural and logical conclusions to be drawn from them:—

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[1] Rosenbach, Notiz uber den Einfluss der Vagusreizung auf die Athmung. Archiv für die gesammte Physiologie, Bonn, 1878, Bd. xvi., S. 503.

1. When the action of the medulla oblongata is removed from the influence of the pneumogastric nerves, as it is after division of both of these nerves in the neck, air is taken into the lungs when the deficiency of oxygen in the medulla has reached the point at which the respiratory sense necessarily generates the stimulus sent to the inspiratory muscles. This action is in no sense reflex, and it depends entirely upon the development, *de novo*, of a stimulation or an irritation in the medulla itself. Under these conditions, the acts of inspiration are abnormally infrequent, and they become excessively prolonged and profound.

In normal respiration, however, it is certain that important reflex influences operate upon the medulla oblongata through the pneumogastric nerves. While there can be no doubt that the stimulus which gives rise to inspiratory efforts is due purely and simply to want of oxygen in the medulla, in order that this stimulus shall operate in accordance with the requirements of the system for oxygen, producing normally from sixteen to twenty inspirations per minute, and varying the number of these movements with different physiological conditions of the organism, depending upon muscular exercise, etc., it is necessary that the respiratory acts should be regulated through the nervous system. Inasmuch as the respiratory acts involve the contraction of the striated muscular fibres, it would be expected that the nerves which regulate them should belong to the cerebro-spinal system. In studying experimentally the influence of various nerves upon the respiratory movements, it is found that the pneumogastrics, which arise from the medulla and are distributed largely to the respiratory apparatus, are closely connected with certain artificially-induced modifications of respiratory action. By applying to these nerves galvanic stimulation of different degrees of intensity, the respiratory movements may be increased or diminished in frequency, or they may be arrested, and these phenomena are always reflex.

Section of both pneumogastric nerves seems to remove the medulla oblongata, so far as its action as a respiratory nervous centre is concerned, from the reflex action of the nervous system; and the respiratory acts then become so far diminished in frequency and are so laboured as to produce serious pulmonary lesions. It is probable that death occurs in a few days after this operation, not alone from abnormal respiratory action, but from a suspension of other important functions which the pneumogastrics have to perform. It is possible, also, that some of the phenomena which are observed in narcotic poisoning, notably the great diminution in the number of respiratory movements, are due to an interference with the respiratory functions of the pneumogastrics.

The precise mechanism of the action of the pneumogastrics in normal respiration, and the exact seat and character of the impressions which serve as the starting point in the reflex phenomena observed, it is difficult to describe within the limits of ascertained facts. If the theory advanced by

Rosenbach be accepted; viz., that the pneumogastrics contain vaso-motor filaments which regulate the quantity of blood passing through the medulla oblongata, the mechanism of the action which takes place in the respiratory nervous centre is readily understood; but the seat and the exact nature of the impression which gives rise to these reflex changes in the calibre of the vessels are still a matter of speculation and conjecture. As far as muscular action in tranquil respiration is concerned, it is necessary to consider only the acts of inspiration, for expiration is produced mainly by the passive action of the walls of the thorax and by the resiliency of the elastic pulmonary parenchyma succeeding the action of the muscles which enlarge the chest and inflate the lungs.

Finally, the respiratory sense, *besoin de respirer*, sense of want of air, or the stimulus which gives rise to inspiratory efforts, is due purely and simply to a deficiency in oxygen in the medulla oblongata, which is the sole respiratory nervous centre. The frequency and the extent of the normal inspiratory movements are regulated and accommodated to the physiological requirements of the system by reflex action operating through the pneumogastric nerves.

In this article, I have endeavoured to set forth the nature and the physiological bearings of my experiments, published in 1877, showing that the sense of want of air is due primarily to a deficiency of oxygen in the medulla oblongata. I have attempted, also, to show how the operation of the stimulus to the inspiratory muscles, which is due to this deficiency of oxygen in the medulla, is regulated, in normal respiration, by reflex action through the pneumogastric nerves. Physiologists are now well acquainted with the functions of the pneumogastrics in connection with the circulation, the action of the stomach and intestines, and certain functions of the liver; but the action of these nerves in normal respiration and the causes of the respiratory phenomena following their galvanization and their section have heretofore been obscure. I venture to hope that my discussion of the reflex function of the pneumogastrics, in connection with the respiratory movements, has thrown some light upon questions which have not been fully understood by physiologists.

ARTICLE IV.

THE DIAPHRAGM: A PROTECTOR OF THE HEART AND CARDIAC VESSELS; ITS INFLUENCE ON THE ORGANS OF CIRCULATION.

A paper read before the College of Physicians of Philadelphia, May 8. By W. S. FORBES, M.D., Fellow of the College, Senior Surgeon to the Episcopal Hospital, and Demonstrator of Anatomy in Jefferson Medical College, Philadelphia.

ON opening the thorax and abdomen in living cats and dogs, while under the influence of ether, for the purpose of examining the motions of